

***Schafer***

## ***APEX Support***

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# **APEX Support**

## **Introduction**

Under the APEX program, Schafer Corporation has been supporting both the Ballistic Missile Defense Organization and the Naval Research Laboratory (NRL) in investigating the potential of using non-linear optical techniques as well as other advanced technologies to improve the performance and/or the system integration and operation of CW high energy lasers, specifically the HF/DF chemical laser. The goal of the APEX program is to provide a CW demonstration of beam clean up using Stimulated Brillouin Scattering (SBS) phase conjugation and to assess its application to the Space Based Laser (SBL) program.

Under the present activity, Schafer Corporation reviewed the status and progress of the activities under the APEX program and performed assessments as to the adequacy and the appropriateness of the APEX program to provide a realistic system impact for the HF/DF chemical laser systems of interest to NRL and BMDO. Specifically, we assessed the status of the SBS cell, the NACL(NAVY/ARPA Chemical Laser) laser, and the connecting optical train to perform a meaningful demonstration and to assess its impact on system performance.

## **System Performance Issues**

Stimulated Brillouin Scattering has the potential to improve the SBL's performance by improving beam quality and reducing jittering through the use of optical phase conjugation. This phenomenon occurs when a high power laser beam is focused within certain fluids, e.g., Xenon, under proper conditions. Electrostrictive coupling between the light and the fluid allows the laser beam to create a region where the refractive index varies spatially in proportion to the focal plane intensity distribution. This variation in refractive index effectively forms a volumetric holographic grating which scatters the light back into the direction from which it came. The strength of this scattering is proportional to the strength of the grating, which is related to the local intensity of the focused laser beam. As this scattered light propagates back it reconverts the intensity into a phase distribution which is the negative of the incoming wave. This returning radiation is therefore the phase conjugate of the incoming beam and has the effect of canceling out perturbations to the beam that have occurred along the portion of the beam path where the return beam remains coincident with the incoming beam. This ability to cancel beam perturbation gives SBS the potential to make improvements in the SBL's operation that could have sweeping implications for the system cost, weight and producibility by

eliminating sensors, deformable mirrors and control electronics. In addition, it would permit relief on optical tolerances for all optics within the conjugated path which in turn could also provide some tolerance relief for optics not in the conjugated path as well.

As part of the assessment of system performance issues, a review of the earlier conclusions from the relevant SBS activities was performed. TRW, under contract from NRL, has conducted several studies and experiments to better understand the potential of SBS to contribute to the SBL. The two most extensive are the Advanced Phased Array Chemical High Energy (APACHE), and the present program called Advanced Phase-conjugation Experiment (APEX).

These programs developed a design concept for the SBL that incorporated SBS as the primary mechanism of aberration control. They addressed several technology issues, including aberration and jitter correction; threshold reduction; flowing cell design; single and multiline SBS; and maser oscillator power amplifier (MOPA) design. In addition tests were performed to demonstrate that CW SBS was feasible. These tests used both pulsed HF lasers (singleline and multiline) as well as long pulsed solid state lasers. These tests when combined demonstrated that CW SBS could be accomplished with no degradation from competing nonlinear effects, that SBS threshold could be reached under achievable laser and xenon operating conditions and that the original concepts could be modified by using threshold reduction techniques to simplify the demonstrations and make them more cost effective. Data from test performed thus far demonstrate corrections for jitter to  $1/25 \lambda/D$ . Beam quality corrections of aberrations as bad as 10 to 15 times diffraction limited were corrected to beam quality of better than 1.1 times diffraction limited. It is also important to note that the bandwidth for these corrections is in the megahertz region, far beyond the reaction time required to correct for jitter or beam aberrations. In addition, beam combination was demonstrated with excellent fidelity.

While the quantitative advantages of an SBL system using SBS will depend on the specific configuration, there are some general advantages one could identify. The SBS configuration offers several potential reductions in complexity of the SBL optics. It would allow the use of a reflaxicon/ reflaxicon pair of optical elements in the ends of the gain region, as opposed to the waxicon/reflaxicon configuration used by the baseline SBL. This offers several advantages. All of the optical surfaces will be conical flats, permitting substantial simplification in the diamond turning fabrication of the optics. This change in the configuration of optical elements has the added advantage of not altering the polarization state of the light. This would eliminate the need for costly phase correcting coating requirements for the optics in the baseline which in turn simplifies the application of coatings for the uncooled optics.

In addition, the SBS concept will relax the alignment requirements, simplify the boresighting and the laser/ATP beam handover process, and significantly reduce system jitter. The effect of thermal distortions in optics, gain medium inhomogeneities, misalignment, etc. that are present in the laser device will all be nearly eliminated. Analysis has shown that beam correction using SBS is far more effective than deformable mirrors in maintaining system brightness for beam wavefront errors caused by degraded mirror coatings. According to the analysis, brightness can be maintained by SBS to absorption levels that are ten times greater than those which can be maintained by adaptive optics techniques. Although the rate of coating failure in this level of degradation is uncertain, the SBS system appears to offer the SBL a longer operational lifetime.

The use of the SBS concept also promises to relax tolerances for optical fabrication of the annular mirrors. Instead of the current diamond turning using the LLNL Large Optic Diamond Turning Machine (LODM), the annular optics could be built up in segments using smaller conventional polishing machines. This could lead to significant reduction in complexity of the optics manufacturing process.

Thus, Stimulated Brillouin Scattering has the potential to offer several advantages to the SBL baseline. By cleaning up aberrations and jitter in the SBL beam, it offers greater brightness at a lower weight and with a potentially smaller diameter beam director aperture. The most important impact of the SBS technology is the relaxation of requirements on other laser systems. If it makes segmented mirrors possible for cylindrical resonators, it would dramatically reduce their cost and increase producibility. Similarly, its ability to compensate for mirror coating degradation could further reduce the cost and increase the producibility of all mirrors in the beam path compensated by the SBS cell. This same quality of compensating for degrading mirror coatings may be useful in making the system more resilient and/or extending its operational lifetime. In addition, SBS technology could also reduce the correction performance required of the fast steering and deformable mirrors in the beam transfer and beam expander assemblies. The use of a high quality master oscillator tuned to a specific frequency could assist in line selection at a very high extraction efficiency. This wide ranging potential of SBS to improve the SBL system is real and the conclusions from all previous activities are still valid.

During this phase of the program there was uncertainty in the focus of the SBL program and thus APEX. System studies and concept development was performed subject to a competitive concept development which was being performed in parallel. Therefore little substantive development of system performance concepts occurred during this phase. Discussions were held on the potential of developing concepts for flight capable SBS systems. Agreements were reached that concepts could be

developed which would allow the SBS system to become flight capable, but no substantive efforts were performed.

## Technology Assessments

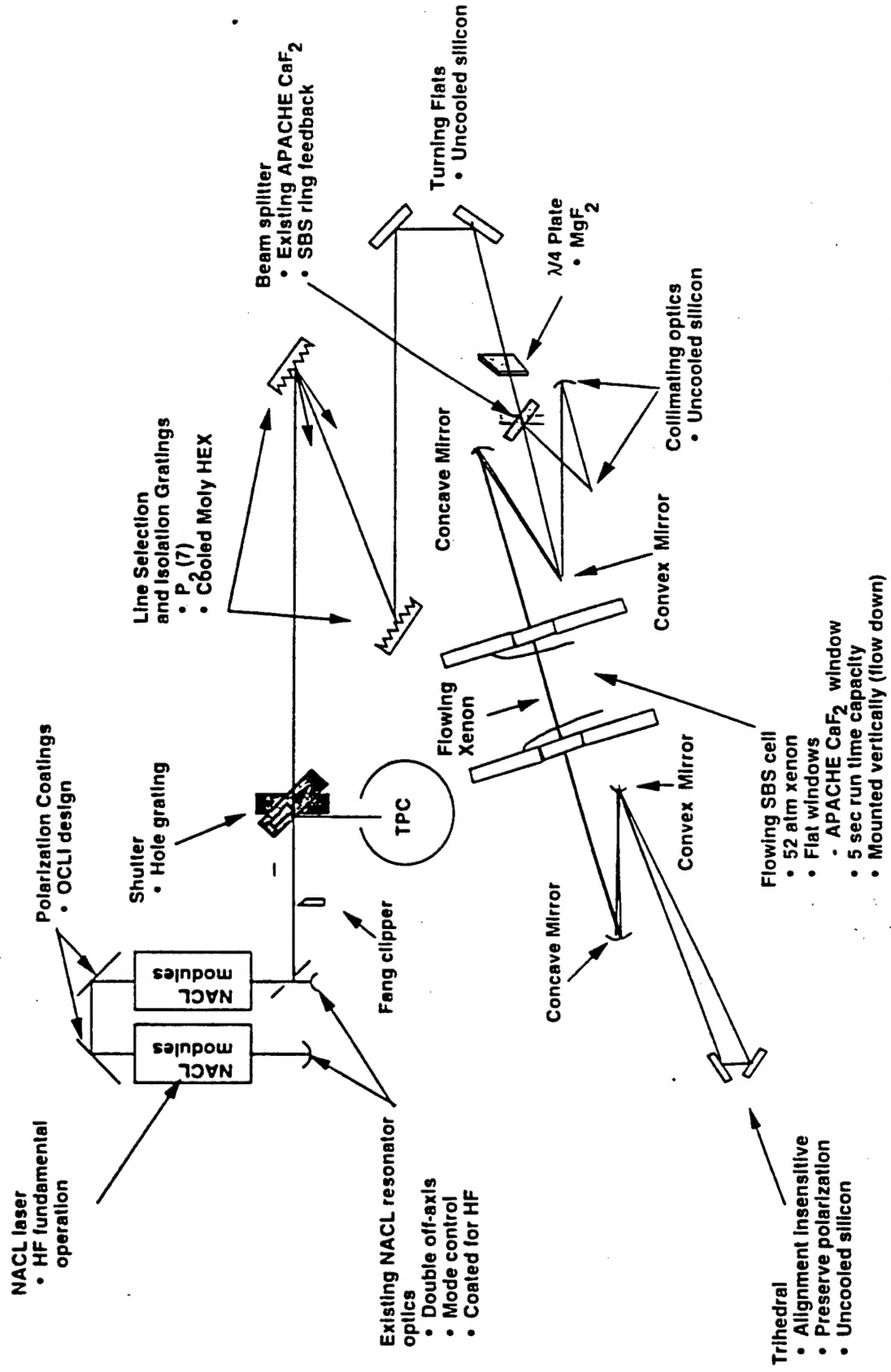
As stated previously, the goal of the APEX program is to provide a CW SBS demonstration using a high power HF laser. The demonstration involves three major subsystems. The high power laser will be the NACL device which will provide the high power optical beam to be phase conjugated by the SBS process. The beam will be transported from the laser to the SBS cell via a high power beam train. This beam train also performs the function of line selecting one laser line to be conjugated and optically isolating the resonator from the phase conjugate SBS return beam. The third subsystem is the SBS subsystem. The SBS subsystem is comprised of an optical ring folded around a high pressure flowing SBS cell. Internal to the SBS cell, the ring will bring the beam to multiple (most likely two) foci. Combined these reduce the SBS threshold power to the point where the NACL beam delivered to the cell can initiate the SBS process. A flowing cell is used to minimize thermal blooming caused by the high power beam focus and to reduce the possibility of gas breakdown. Figure 1 is a schematic of the entire optical beam train for the NACL SBS experiment.

During the period of performance of the task some work was performed to finish the plumbing required for recapturing the xenon from SBS cell as well as assessing the optical beam train optics and completing the beam duct hook ups. In addition TRW (on their own funds) completed the new data recording system for NACL which should simplify its operation and data collection. Towards the end this period of performance the decision to proceed with the experiment was made and the approach taken to date was confirmed. Below is a description of the equipment and its status.

The NACL device was converted from DF to HF operating wavelength and reactivated in April 1992. Tests performed by TRW at that time were an outstanding success with the exception of the power produced. The out coupled power was approximately 50% of that predicted from both the scaling of the NACL module closed cavity data and both TRW and Schafer code predictions. This was accompanied by a reduced mode width from 2 cm versus the expected 3 cm which was predicted, and an apparent upshift in the laser spectrum by an entire J line.

In spite of this, the NACL beam quality was excellent, nominally diffraction limited. This is consistent with good mode control and is critical for the SBS demonstration. Poor beam quality or loss of mode control would otherwise raise the power threshold for the SBS process and have significant negative impact on the demonstration. The beam quality measurement agreed with prediction.

# NACL SBS Experiment Concept



The resonator turning flats had polarization coatings so that the resonator output would be linearly polarized. This facilitates the optical isolation of the SBS return from the outgoing resonator beam as the return will be polarized in the orthogonal plane. This mitigates the concern that the SBS return, if allowed to find its way back into the resonator, might degrade resonator mode control. The tests demonstrated that the output was linear polarized (>97%) and very stable in that there was very low jitter.

In order to understand the reduced power, several issues were assessed. These included reflectivity degradation of mirrors, excessive heat release in the cavity and mismatched gain widths. The principal cause of the power and mode width degradation is most likely caused by excessive heat release in the cavity. This could result either from fluorine atom recombination in the combustor or from thermal choking. The remedy is the same in both cases and leads to simple fixes. Namely, increase the diluent ratio and increase the cavity shroud angle. The latter is not mechanically a problem since the shrouds were designed with an adjustable angle mechanism. During the period of performance of this task, these conclusions were reviewed but no work was performed on NACL. The remaining improvements to NACL will occur during the reactivation process just prior to the now approved CW SBS demonstration.

While NACL HF performance as measured in the 1992 tests show that NACL is sufficient for the present demonstration, it could limit the time of operation. This is caused by the increase in optical aberrations which will occur with increased operating time during the experiment. These aberrations will be caused by thermal effects of the optics and xenon gas and their overall effect will be to increase the power required to keep the SBS process above threshold. Thus, increasing NACL power without degrading any other performance parameters would increase the time of the SBS demonstration. Many of the improvements to NACL were performed as joint Schafer/TRW designs and assessments.

During the assembly of the SBS cell, Schafer Corporation participated closely with TRW as the review and assessment function. In the early stages, we reviewed the designs for compliance to the fluid dynamic and cleanliness requirements. As a result of this review, TRW changed the cell flow direction from the original flowup to flowdown. This would minimize the flow inhomogeneities which could be caused by buoyancy force. Changes were also made to the cleaning procedures, system bakeout concepts, xenon discharge and refill concept and several structure/safety concepts. All were critical. The first three can impact the contaminant issues critical to reducing water vapor and particulates which can lead to absorption or breakdown. Either of these could have calamitous effects on the SBS process.

The last two are key issues for a 52 atmosphere cell which can have unbalanced loads if not properly operated. Because of the requirement for high pressure, low birefringent calcium fluoride windows (for the high power laser beam), as well as diagnostic windows for cell characterization, great care must be taken to develop concepts which can minimize xenon loss in case of window breakage while protecting people and high value optical components while not impacting optical performance.

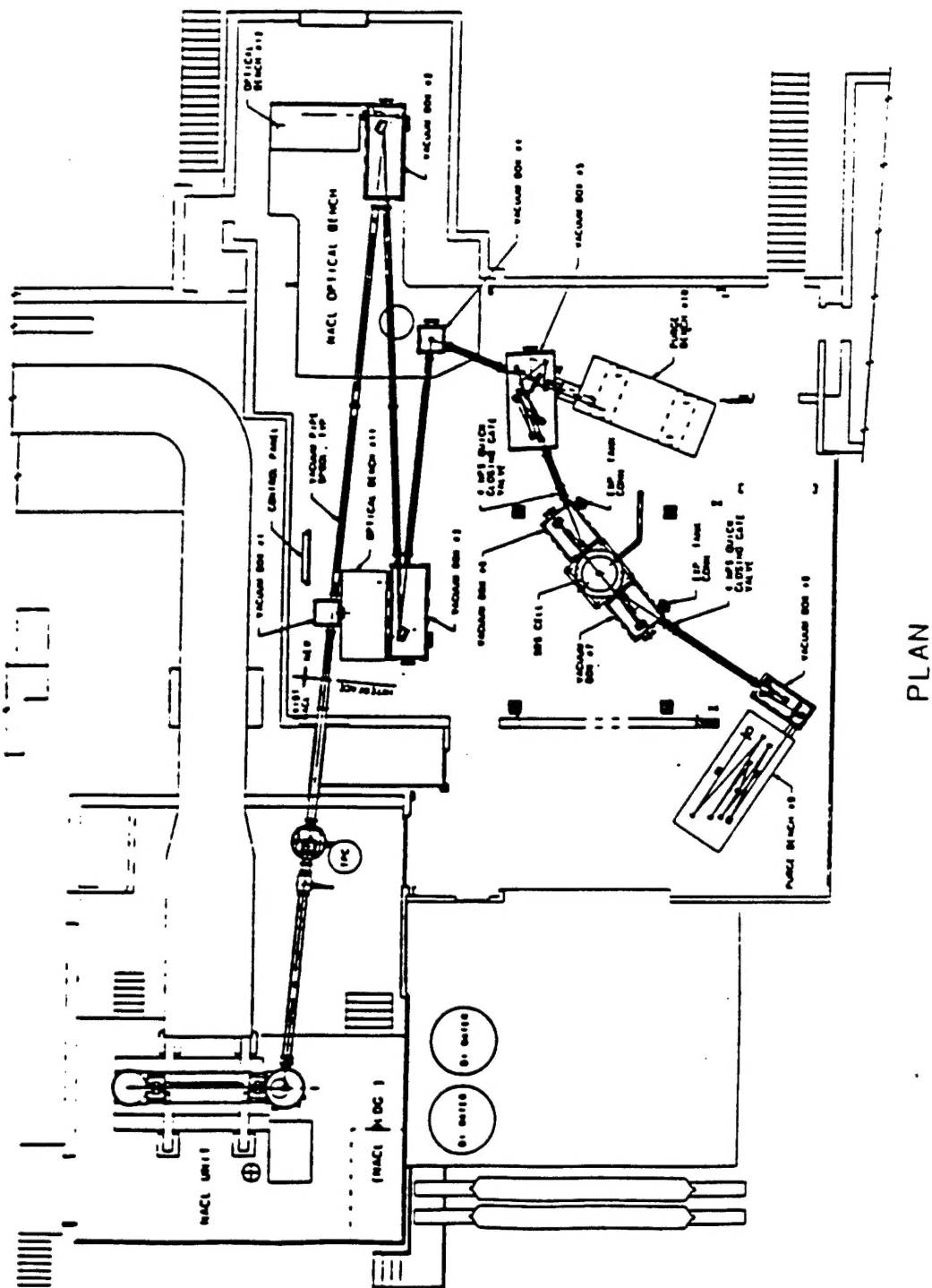
Schafer participated in assessing TRW's plans for integrating and testing the flowing cell and reviewing the test results. During the period of performance of this task, we further reviewed the test results but no work was performed on the SBS system other than to assure the interfaces to the high power optical beam train are consistent with designs. In addition some work on the SBS cell relating to building the xenon recovery system was completed.

The last key element is the development of the high power optical beam path which connects the NACL laser to the SBS cell. The schematic is shown in Figure 1, while the top level layout drawing is shown in Figure 2. Schafer personnel have reviewed the TRW drawing package and discussed plans and changes as required. We also reviewed the placement of diagnostic ports to assure access during the alignment phase, the NACL reactivation phase and the full-up SBS demonstration. TRW has performed a very credible and careful job of assuring proper access for diagnostics, alignment and beam control during all phases. During this phase, they have completed all optical layouts and the mirror cans and optical benches have been fabricated and positioned. The benches have been isolated from the deflections caused by pulling vacuum in the optical cans. The opto-mechanical components have been completed. The optical ducts have been installed. The diagnostic benches are in place and adequate diagnostic ports provided. The optical substrates have been polished, but the silicon substrates have not been coated and the gratings have not been ruled.

The decision to complete the system and perform the demonstration is timely as all of the elements are available. The key areas to be addressed relate to NACL power and mode width which will be addressed during the reactivation, grating manufacturing (still a risk issue) and cell operation with xenon. All can be achieved this year with proper attention and funding.

The last remaining issues will be the adequacy of the diagnostics. The APEX demonstration will stress the diagnostic capacity of the CTS test site and careful attention will be needed to schedule use of diagnostic equipment.





**Figure 2**